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PROBLEM SOLVING WITH LIMITED INFORMATION.(U)

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

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1. REPORT NUMBER: (14) CRTL-TR-5
2. GOVT ACCESSION NO. (12)
3. RECIPIENT'S CATALOG NUMBER (9)
4. TITLE (and Subtitle): (6) Problem Solving with Limited Information.
5. TYPE OF REPORT & PERIOD COVERED: Final Report, 1 May 1973 - 31 Jan 1977
6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s): (10) Dr. Bruce M. Ross
8. CONTRACT OR GRANT NUMBER(s): (15) N00014-75-C-0983
9. PERFORMING ORGANIZATION NAME AND ADDRESS: Center for Research in Thinking & Language, Dept. of Psychology; Catholic University, Washington, D.C. 20064
10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: NR-197-025
11. CONTROLLING OFFICE NAME AND ADDRESS: (12) 14p.
12. REPORT DATE: (11) May 1977
13. NUMBER OF PAGES: 16
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)
15. SECURITY CLASS. (of this report): Unclassified
15a. DECLASSIFICATION/DOWNGRADING SCHEDULE
16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

DDC JUN 16 1977 C

18. SUPPLEMENTARY NOTES
19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

deductive logic, inference, problem solving, reasoning, thinking (psychology of)

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This is the final report of Contract N00014-75-C-0983. The report briefly summarizes the findings and main conclusions of the four technical reports issued under the contract. The goal of ~~the~~ this contract was to study deductive thinking where ~~the~~ information available to a reasoner was limited by virtue of being incomplete. The incompleteness in the information arose because, as is typical of most real-life situations, only a sample of all ~~the~~

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possible logical expressions that could be formulated from a number of independent dimensions were assigned truth values. Empirical studies with college students were carried out with a previously formulated concept-attainment model that allowed for multiple concept solutions. Using both a concept-production and a concept-recognition format several factors influencing success in concept attainment were isolated.

A novel logical model for instance deduction, the obtaining of valid instances from concepts, was formulated. The model complemented the previous concept-attainment model. Extensive empirical studies were carried out based on the instance deduction model. A case-study approach to several sessions of performing instance deductions was undertaken as well as production and recognition experiments with groups of observers. The conclusion was reached that the instance-deduction treatment described by the previously formulated model -- which was in accord with acknowledged canons of formal logic -- could easily be acquired by untrained participants and lead to quick improvement in making practical deductions. Theoretical analysis concentrated on two comparisons in the logical structure of problems: (1) between conjunctive and disjunctive concepts; and (2) between conjunctive and disjunctive instances. Only the second distinction was found to be important. Factors were described that relate to the difficulties individuals experienced in dealing with disjunctive instances.

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SUBJECT: Final report of work completed under the support of Contract N00014-75-C-0933, Work Unit No. NR 197-025, between the Catholic University of America and the Engineering Psychology Programs, Office of Naval Research.

I. This report constitutes a final description of work completed under the support of Contract No. N00014-75-C-0983, Work Unit Number NR 197-025, between the Catholic University of America and the Engineering Psychology Programs, Office of Naval Research. The contract was initiated 1 May 1973 and (with a nine-months, no-cost extension) terminated 31 January 1977.

II. The aim of the contract was to study deductive thinking under conditions of limited information from both a theoretical and empirical standpoint. The theoretical perspective resulted in logical models of deduction that were used in designing and analyzing problems administered to observers in the empirical phase of the research. Four technical reports, listed at the end of the present report, were completed and distributed.

III. The present report is divided into five sections. Three short sections (A, B, and D) are concerned with the rationale and justification of the research. Two longer sections (C and E) describe the empirical work carried out under the contract.

A. General Rationale for Studying Deductive Problem Solving

Individuals often have information available to them from which they should be able to draw straightforward conclusions with logical certainty. Yet they frequently fail to do so, even though memory is not involved and valid implications are placed in a list among other solution alternatives. In our research these considerations led to an attempt to answer three general questions: (a) What kind of biases prevent implications from being evaluated correctly? (b) What types of problem solving strategies are commonly invoked? (c) To what extent can the use of three or four simple rules for deduction facilitate correct deductions?

To avoid misunderstanding, it should be emphasized that deductive reasoning in the form that we have studied it is usually at a simpler level than that undertaken with probabilistic decision making. Indeed, some deductions are often necessary before probability calculations are worth performing. Further, in many situations it is desirable to know the qualitative possibilities that are logically feasible with regard to whether a quantitative probability can be attached to each individual possibility. That is to say, drawing deductions sometimes yields a first approximation in describing problem solutions where only partial information is available. With strong time pressure this approximation can be in itself sometimes sufficient to encourage or eliminate a course of action.

A practical example of drawing deductive conclusions in a nautical setting was furnished by describing the use of deduction in target surveillance based on multiple sightings. In such an example the deductive basis for drawing conclusions is not always limited to cases where physical objects exist, since negative examples (nonexistent configurations) can also play a role in deductive inferences.

B. Advantages of the Deductive Models used in the Experiments

In the first experiments work was based on a previously formulated logical model for presenting concept-attainment problems (Mott & Ross, 1968). By concept-attainment is meant the deduction of logically valid concepts from sets of positive and/or negative instances. In work performed under the contract a model was also

developed for concept instantiation (instance deduction) problems (Mott & Ross, 1975). Instance deduction refers to the identification of valid instances of a set of one or more concepts. This instance deduction model was applied to the later experiments of the contract. (Gurney & Ross, 1977; Ross & Gurney, 1975).

In general, both of the above logical models incorporated three major advantages for the design and analysis of deductive problem solving experiments over previous paradigms described in the psychological literature.
These advantages are:

(1) Multiple correct solutions, often of different logical types, were correct within the same problem.

(2) Both concepts and instances (and therefore problem solutions) could be either conjunctive or disjunctive in form depending on the problem design the experimenter chose.

(3) Valid solutions could be drawn from incomplete instantiations. This generalization meant that, in accord with most real life situations, only a sample of all possible instances (concepts) needed to be specified as positive or negative, and yet logically consistent solutions could be determined.

C. Empirical Results for Concept Attainment

1. Concept-Attainment Production Experiment

Observers (N=24) were presented problems (sets of instances) that each allowed two or more correct concepts to be attained. Minimal instructions were given to present possible solution types rather than to illustrate deductive rules to follow. Two conditions were administered, a Specified condition where the number of correct solutions that could be obtained for each problem was printed and an Unspecified condition where no solution numbers were printed. (Note that participants in this experiment and all others to be reported were male and female college students with the exception of the addition of a few university staff members in one experiment.) Four conclusions were reached. One, the Specified group produced many more correct and incorrect solutions than the Unspecified group. This was especially true for the production of correct 1st-order conjunctive concepts (A and B). Second, there was a marked reluctance on the part of individuals in the Unspecified group to produce more than two concepts per problem regardless of the number of correct concepts. Third, both Specified and Unspecified groups produced few 1st-order disjunctions (A or B), but they produced far too many 2nd-order

disjunctions (AB <u>or</u> C; AB <u>or</u> CD) that were needlessly complex. This frequent listing of nonessential values among attained concepts suggested that observers often confused concept instances with the concepts themselves. Fourth, individual performance range was very wide; from 2 to 19 correct concepts were obtained out of a possible 24.

(Technical Report CRTL-TR-1)

2. Concept-Attainment Recognition Experiment
Instructions were more detailed than for the previous experiment. Four worked-out practice problems, with four concepts for each problem, were included in the instructions. A total of 20 correct and 22 incorrect concepts were distributed over 10 concept-attainment problems. Observers (N=40) encircled Yes or No, giving a 50% chance level of correctness.

An approximate 80% or better level of correctness was obtained for 0-order concepts (A alone), 1st-order conjunctive concepts (both with 2 and with 3 values), and 1st order disjunctions (both with 2 and with 3 values). Again participants did poorly with 2nd-order disjunctions recognizing correctly only 58% of these concepts. It was concluded that naive observers performing with a recognition format can assimilate logical instructions sufficiently to attain concepts with a single logical operator at a satisfactory level of proficiency.

(Technical Report CRTL-TR-1)

D. Specific Rationale for Studying Instance Deduction

The other studies performed under the contract were devoted to theoretical and empirical investigations of instance deduction. This area has received little previous attention in the psychological literature. Usually instances have been defined in such a narrow range, most often as 2-dimensional conjunctive concepts, that to ask for instance deduction would be trivial. With the present deductive system, however, permitting both disjunctive and conjunctive instances of both the 1st- and 2nd-order, the deduction and identification of positive and negative instances can be a challenging problem.

Nevertheless, there are two ways in which instance deduction is a simpler, more direct process than concept attainment. This being the case, studying instance deduction can often be a better vehicle for understanding participants' reasoning than concept attainment. At the same time the study of instance deduction is of interest in its own right since individuals can hardly be considered to understand a concept if they can't clearly identify positive and negative instances of the concept. The first way in which instance deduction is more direct is that each concept is considered individually as possessing multiple instances. Thus deduction is on a single-step basis even when instances must be valid for several concepts. In contrast, concept attainment is more complex in that (except for redundant instances) all instances are interrelated with a modification in implied concepts for each new instance that is added.

The second way in which the instance deduction process is simpler than concept attainment is that negative instances do not have to be considered simultaneously with positive instances, nor is all-negative instantiation a feasible procedure as it is with concept attainment. Negative instances for instance deduction are just the remaining instances that are not valid for any concepts after determination of whether such instances can be positive for these concepts. Since there is little flexibility in procedure when performing instance deduction, deductive processes are more straightforward and possibly easier to understand than they are for concept attainment where a variety of approaches is possible in solving the same problem.

(Technical Report CRTL-TR-3 presents an account and justification of instance deduction in formal-logic terminology.)

E. Empirical Results for Instance Deduction

1. Instance-Deduction Production Experiment

Ten problems that listed sets of concepts were presented to observers ($\underline{N}$=30) who were required to supply two instances per problem. Whether instances were to be conjunctive or disjunctive was specified; six of the problems specified a mix of one conjunctive and one disjunctive instance. Four matching rules were supplied to the participants relating to the four possible combinations of conjunctive and disjunctive instances and concepts. The number of correct instances given per individual ranged from 2 for two observers to a perfect 20 for three observers. The two individuals who scored only 2 would have produced 8 correct instances if a minor error of incompletely specifying all dimensions was overlooked. However scored, it was evident that this experiment like the concept-attainment production experiment resulted in a very large range of scores making the drawing of general conclusions from production experiments more difficult than recognition experiments.

Mean accuracy reached was quite high, as might be expected since each set of concepts had many more than two correct instances. Notwithstanding, a significant difference was found between correct production of conjunctive instances (84%) and disjunctive instances (71%). Greater mean accuracy was also shown for production of conjunctive instances on a per problem basis when both conjunctive and disjunctive instances were requested in the same problem. On the other hand disjunctive concepts did not appear to be more difficult to deduce instances from than were conjunctive concepts. These results suggested that it was not difficulty in understanding disjunctive concepts per se that caused problem difficulty in the expanded instance-deduction experiment to be described next or in the following instance-recognition experiments. More exact comparisons based on this theme were made at a descriptive level. Two factors were especially noted as producing errors in instance deduction. One was the obvious tendency for errors to increase as number of concepts increased. More interesting was the finding that heterogenity

of concept levels in the same list (a mixture of 0-order, 1st-order, and 2nd-order concepts) tended to cause more error than when all concepts were at the same level (eg., all 1st-order concepts).

(Technical Report CRTL-TR-1)

The total N for the above experiment was increased to 54 by adding 22 more college students as observers. Three of the 10 instance-production problems were of interest in order to make a clear comparison between difficuity of conjunctions and disjunctions. In a between-problem comparison (3 disjunctive concepts given and 2 conjunctive instances requested versus a second problem with 3 conjunctive concepts given and 2 disjunctive instances requested) significantly fewer errors were made with conjunctive instances. The same result was obtained with an intraproblem comparison where both disjunctive and conjunctive concepts were listed and both types of instances were requested. Another point to emphasize is that the more accurate production of conjunctive instances went counter to probability expectations since there were almost always many more valid disjunctive than conjunctive instances. It was concluded that with these rather tightly controlled comparisons it was not the misunderstanding of disjunction as such but the specific inability of the subjects to formulate disjunctions as instances of concepts that increased errors.

(Technical Report CRTL-TR-2)

2. Instance-Deduction Recognition Experiment

This experiment was carried out on a larger scale than the others with a total N of 155 observers. There were 10 problems with a total of 42 instance recognitions. Participants were divided into three groups. A Double-Scan Rule group (N=53) had available the four rules used in the instance-production experiment. A Double-Scan Naive group (N=64) and a Single-Scan Naive group (N=38 had no deduction rules available to them. The difference between the double-scan and single-scan procedures was that with the double-scan procedure participants made two passes through the problems.

On the first pass observers indicated whether an instance was or was not a positive instance of all the listed concepts; on the second pass they indicated whether the remaining concepts were instances of some or none of the concepts (although they could also change their minds about their original judgments). With the single scan procedure all, some, or none judgments were made on the initial reading of a problem.

There was a significantly better performance for the rule conditions with 30.9% error, as compared to 39.0% error for the Double-Scan Naive group and 38.4% error for the Single-Scan Naive group. Interesting differences were found in response usage. Rule-using observers tended to overuse the affirmative "all" response while naive observers underused it. For the naive groups, the single-scan group overused "some" and the double-scan group the "none" response. Thus to some extent a psychological set appeared to be induced that was only partly dependent on performance level. At the same time, though favoring the yes response, the rule group had errors fairly evenly distributed over the three response categories, an outcome that mirrored correct response proportions. The finding, noted above in the instance-production experiment, of much easier identification of conjunctive instances from disjunctive concepts as compared to the converse identification of disjunctive instances from conjunctive concepts was highly supported for the recognition results.

The real force of the comparison between disjunctive and conjunctive instances in the production and recognition experiments was that the matching rules given to observers to make both comparisons were almost identical; the only difference was that there was a reversal of concept and instance as to which was disjunctive and which conjunctive. (In the four rules given in the instructions the rules involved were Nos. 2 and 3.) Taken altogether, the results suggested that it was the use of disjunctions as solution outcomes that made for performance difficulty rather than failure to comprehend the meaning of disjunction. A descriptive model was outlined in which subjects first treated all instances as conjunctions and subsequently, if required, derived disjunctions from these conjunctions. In this model, it is the fact that obtaining disjunctive instances is frequently a two-step process that increases errors.

(Technical Report CRTL-TR-2)

3. Intensive Analysis of Observers' Performance of Instance-Deduction Recognition

Five major contrasts can be drawn between this experiment and the previously reported experiments. One, problems were presented at the observer's convenience on a CRT-scope display and answers were automatically recorded. This is in contrast to the paper-and-pencil booklet format of previous experiments. However, printed matching rules were again available as they had been in the prior experiments. Two, correctness feedback was given automatically following every instance recognition (all, some, or none responses) while no feedback was administered in earlier experiments. Three, problems were administered to the same individuals for five sessions (actually there were eight sessions in all but three early sessions administering easier problems were omitted from analysis) rather than the single-session administration of the other experiments. Four, reaction-time measures from time of display to time of responding were taken, whereas none had been taken previously. Five, all listed concepts for which instances were to be identified were complex in that they were all either 2nd-order conjunctions or 2nd-order disjunctions. Concepts for a particular problem were all-conjunctive, all-disjunctive, or mixed. Previous experiments had only a few problems consisting exclusively of 2nd-order concepts. The present experiment had 13 problems with the same 10 instances listed for each problem, making a total of 130 instance recognitions for each session. The price that was paid for the large amount of data generated by each observer was to restrict the number of participants to three, which put analysis on a case-study basis rather than that of statistical averages as had been true for the earlier experiments.

Two diverse styles of problem solving were delineated by observer performance. As sessions progressed, two of the participants appeared to take an "abstract" approach leading to large step increases in accuracy, particularly in correctly identifying disjunctive instances. The other observer pursued a more "concrete" rote learning approach with gradual, though significant accuracy increases. Further, this individual did not show any especially large improvement with disjunctive instances. The "abstract" observers terminated with an overall success rate of near 90% while the "concrete" observer achieved 68% correctness in the last session. Thus some success was achieved even with an inferior approach.

The results obtained from error tallies were paralleled by reaction-time measurements compiled separately for each session and problem type. The "concrete" observer who responded faster than the "abstract" observers only during the first session also showed less differentiation in responding to disjunctive and conjunctive instances throughout all sessions. For all participants there was a steady decrease in reaction times from the first to third sessions followed by quite level mean reaction times for the remaining two sessions. Reaction times did not completely reflect observer performance since correctness continued to improve in sessions 4 and 5 for one "abstract" observer and the "concrete" observer. The other "abstract" observer had obtained near perfect correctness by session 3.

In support of the notion that concepts, in contrast to instances, are at about the same level of difficulty whether disjunctive or conjunctive, no reaction-time differences were found between all-disjunctive and all-conjunctive concept problems. As compared to the previously obtained results achieved on a one-session basis (CRTL-TR-2), a successful demonstration was given, that the described system of instance deduction whose only pedagogical feature was knowledge of results significantly reduced errors for untrained observers dealing with moderately complex concepts. Therefore a main conclusion was that given matching instructions, exposure to problems, and correctness feedback considerable instance-deduction improvement can occur without the need for any individualized instruction.

(Technical Report CRTL-TR-4)

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<u>List of Techical Reports Issued under the Contract</u>

TR-1 Ross, B.M., Locker, R., & DeLisi, R. Deductive Problem Solving with Limited Information. Center for Research in Thinking and Language, Catholic University, March 1974, 36 pp. (AD 777 067)

TR-2 Ross, B.M., & Gurney, R. The Deduction of Concept Instances with and without Rules. Center for Research in Thinking and Language. Catholic University, March 1975, 36 pp. (AD A008 240)

TR-3 Mott, T.H., Jr. & Ross, B.M. A Logical Description of the Deduction of Instances from Concepts. Center for Research in Thinking and Language, Catholic University, May 1975, 43 pp. (AD A010 878)

TR-4 Gurney, R & Ross, B.M. Sources of Difficulty in Deducing Instances from Concepts. Center for Research in Thinking and Language, Catholic University, May 1977, 28 pp.

Mott, T H. Jr., Gurney, R., & Ross, B.M. <u>A logical model for instance deduction experiments</u>. Submitted to Journal of Mathematical Psychology for publication.

<u>Additional Reference</u>

Mott, T.H., Jr., & Ross, B.M. An application of truth functional logic to concept-attainment experiments. Journal of Mathematical Psychology, 1968, <u>5</u>, 470-495.

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